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Published in:
Proceedings of the Third Middle East-North Africa Renewable Energy Conference (on CD-ROM)

Publication date:
2006

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Citation (APA):
Mortensen, N. G., Said Said, U., & Badger, J. (2006). Wind Atlas for Egypt. In *Proceedings of the Third Middle East-North Africa Renewable Energy Conference (on CD-ROM)*

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Wind Atlas for Egypt

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Executive Summary

The results of a comprehensive, 8-year wind resource assessment programme in Egypt are presented. The objective has been to provide reliable and accurate wind atlas data sets for evaluating the potential wind power output from large electricity-producing wind turbine installations. The regional wind climates of Egypt have been determined by two independent methods: a traditional wind atlas based on observations from more than 30 stations all over Egypt, and a numerical wind atlas based on long-term reanalysis data and a mesoscale model (KAMM). The mean absolute error comparing the two methods is about 10% for two large-scale KAMM domains covering all of Egypt, and typically about 5% for several smaller-scale regional domains. The numerical wind atlas covers all of Egypt, whereas the meteorological stations are concentrated in six regions. The Wind Atlas for Egypt represents a significant step forward in the application of the wind atlas methodology in Egypt. Not only does it provide a coherent and consistent overview of the wind energy resource over the entire land (and sea) area of Egypt, the results of the mesoscale modelling are further available in a database (numerical wind atlas) which may be employed directly for detailed wind resource assessments and siting of wind turbines and wind farms. Utilising this database together with elevation maps derived from the Space Shuttle Topography Mission and land-use maps constructed from satellite imagery, the wind resource and likely power production of a given wind farm can be estimated in a matter of hours – anywhere in Egypt. In addition to the very high wind resource in the Gulfs of Suez and Aqaba, the wind atlas has discovered a large region in the Western Desert with a fairly high resource – close to consumers and the electrical grid. The KAMM simulations seem to capture the main features of the wind climate of Egypt, but in regions where the horizontal wind gradients are large, the uncertainties are large as well and additional measurements are required. The results are now published in a Wind Atlas for Egypt.

1. Introduction

With a currently installed capacity of about 145 MW – corresponding to less than 1% of the electricity consumption – wind power is still in its infancy in Egypt. But the goals for the future have been set higher: 850 MW in 2010 (3%) and 2750 MW in 2020 (6%). In order to effectively meet these goals, Egypt is not only committed to refine and strengthen the legal and regulatory framework governing wind power in Egypt, but also to provide the necessary reliable background information on the geographical variation and magnitude of the Egyptian wind resource. A milestone in this development is the *Wind Atlas for Egypt* which was published recently by the New and Renewable Energy Authority (NREA) and the Egyptian Meteorological Authority (EMA) in Cairo, in cooperation with Risø National Laboratory.

The Wind Atlas for Egypt is one of the first – and certainly the most comprehensive – numerical wind atlases ever established. The wind resource over an area of more than one million square kilometres – much of which consists of mountains and remote desert tracts – has been determined by two independent methods: a traditional wind atlas based on observations from more than 30 stations all over Egypt, and a numerical wind atlas based on long-term reanalysis data and a mesoscale model. The wind atlas allows for wind resource assessment and siting anywhere in Egypt, and further provides bankable resource estimates in the most promising regions.

The New and Renewable Energy Authority (NREA) was founded in 1986, with the aim to boost solar, biomass and wind power production. NREA's target is to increase the share of renewable energy sources (RES) to 3% by 2010. At the Conference on Renewable Energies in Bonn in June 2004, Egypt affirmed its commitment to increase this share to 14% of the country's installed capacity with renewable energy by 2020-2025, the nominated value will be divided into two portions 7% from hydro, 7% from wind and solar energies. The targets include the installation of 3,000 MW of hydropower, 2,750 MW of wind power and 750 MW of solar-thermal generation capacity.

The present paper describes the methodology applied in the Wind Atlas for Egypt project and summarises the results obtained.

2. Observational wind atlas

The conventional method employed to produce estimates of the wind resource on a national scale is to analyse wind speed and direction measurements made at a number of sites around the country as in for example the European Wind Atlas. More than 30 meteorological stations have been analysed in the Wind Atlas for Egypt, see Figure 1.

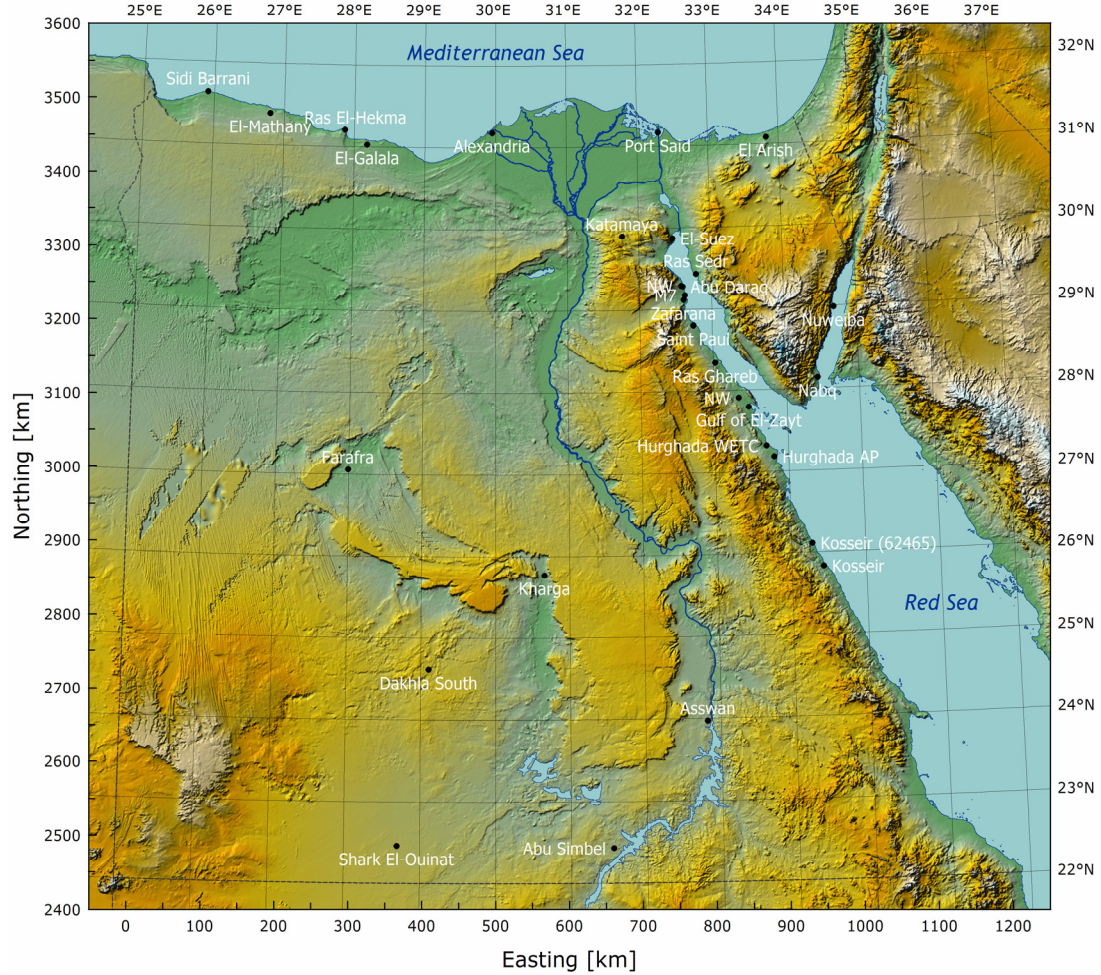


Figure 1. Meteorological stations used for the Wind Atlas for Egypt (2006). The elevation map was derived from Space Shuttle Topography Mission 30 arc-sec. data.

Twenty-two of these stations were erected specifically for the wind atlas investigation and feature masts between 25 and 47 m; eight are standard (WMO) stations with a 10-m mast. The measurement series are between one and 14 years long. The measurement sites were selected to cover six regions: the Northwest Coast, the Northeast Coast, the Gulf of Aqaba, the Gulf of Suez, the Red Sea and the Western Desert. The sites were chosen to represent the most promising areas for wind energy exploitation, as well as to provide information on all significant types of wind climatology in

Egypt. Logistical aspects have limited the site selection somewhat as large parts of the Western Desert and mountainous areas are fairly inaccessible.

The wind measurements have been analysed according to the *wind atlas methodology* in order to make them suited for wind resource assessment and siting, see Figure 2. First, the time-series of wind speed and direction are converted into a wind rose and the associated sector-wise wind speed distributions, i.e. the *observed wind climate*. Secondly, meteorological models are used to transform the site-specific observed wind climate into a site-independent *regional wind climate* (the ‘up arrow’). The regional wind climate is often representative of an area of 100-1,000 square kilometres around the station; in this region it is therefore possible to infer the *predicted wind climate* at any site (and any height) by applying the same models in reverse (the ‘down arrow’). Given the predicted wind climate, it is straightforward to derive the predicted power production of a single wind turbine or wind farm.

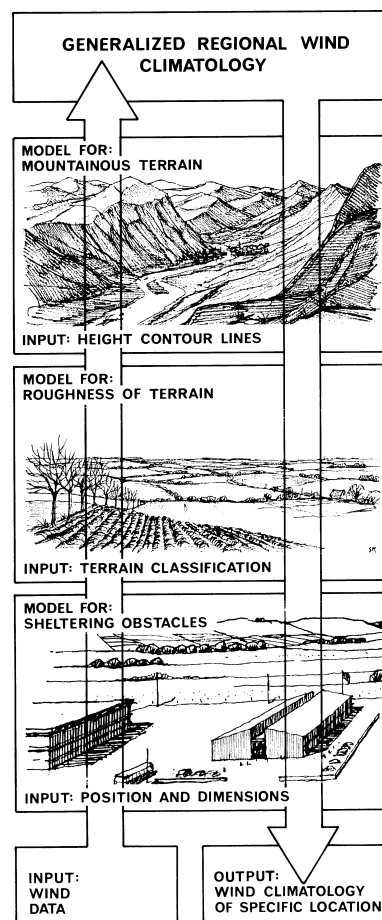


Figure 2. The wind atlas methodology.

The wind atlas models take into account – and therefore require information about – the elevation differences of the terrain, the different surface conditions and the shelter effects due to buildings and other nearby obstacles. The Wind Atlas for Egypt has made extensive use of Shuttle Radar Topography Mission elevation data for constructing detailed height contour maps around the stations, and of satellite imagery (Google Earth) for mapping the land-use and surface roughness conditions. Sheltering obstacles were identified from satellite imagery and during site visits.

The observational wind atlas is based on more than 150 ‘measurements years’ measured at 30 stations; corresponding to more than 5 million wind observations. Figure 3 compares the regional wind climates determined at the 30 stations; here the mean wind speed and power density at 50 m a.g.l. over terrain of roughness class 1 ($z_0 = 0.03$ m) are used for the comparison.

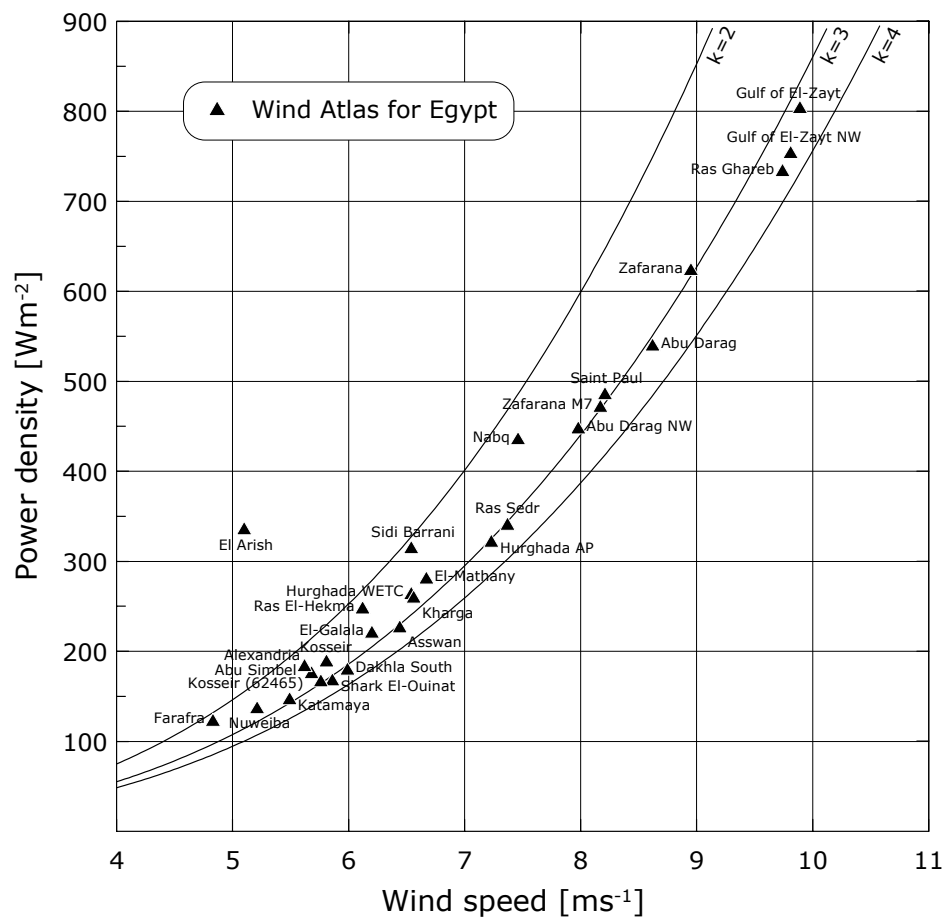


Figure 3. Mean wind speeds and power densities at a height of 50 m over roughness class 1 ($z_0 = 0.03$ m) for the 30 stations in the Wind Atlas for Egypt.

Figure 3 confirms the existence of a widespread and particularly high wind resource along the Gulf of Suez: almost all the stations with a mean atlas wind speed above 7 ms^{-1} are located here. A standard MW-size wind turbine erected at one of the most favourable sites in the southern part of the Gulf of Suez (Gulf of El-Zayt area) would experience an average annual wind speed of more than 11 ms^{-1} (at 50 m a.g.l.) and would run at rated power for more than 6000 hours in a year – corresponding to a capacity factor of almost 70%!

3. Numerical wind atlas

With 30 meteorological stations it is only possible to map the wind resource in detail over a few tens of thousands of square kilometres with an observational wind atlas. Numerical wind atlas methodologies have been devised to solve the issue of insufficient wind measurements. For Egypt, we have used the so-called KAMM/WAsP method developed at Risø. The KAMM (Karlsruhe Atmospheric Mesoscale Model) is a mesoscale model that models the wind flow on a much larger scale than the wind atlas model WAsP; typical domain sizes are between 100,000 and 1,000,000 square kilometres.

The mesoscale model works much like a weather forecast model – in the sense that it estimates how the terrain influences the wind flow and other characteristics of the atmosphere – but the models are employed in different ways. The weather forecast model uses an analysis of today's meteorological observations in order to produce a weather forecast, while the mesoscale model can use sets of historical analyses in order to estimate the mean meteorological conditions over the entire modelling domain. For Egypt, we have used statistics of the large-scale meteorological situation for 34 years to estimate the long-term wind conditions in the grid points of the mesoscale model. The distance between these grid points is 7.5 km for the two domains that cover all of Egypt, corresponding to more than 50,000 grid points in the domains. Based on these estimates of the wind climate, we can draw a wind resource map of Egypt, see Figure 4. The wind resource map provides an overview of the climatological wind conditions over Egypt, but the accuracy in the resource estimates for any specific site is limited because it does not take all the small-scale features of the terrain into account; the map is based on simple interpolation between the grid point values.

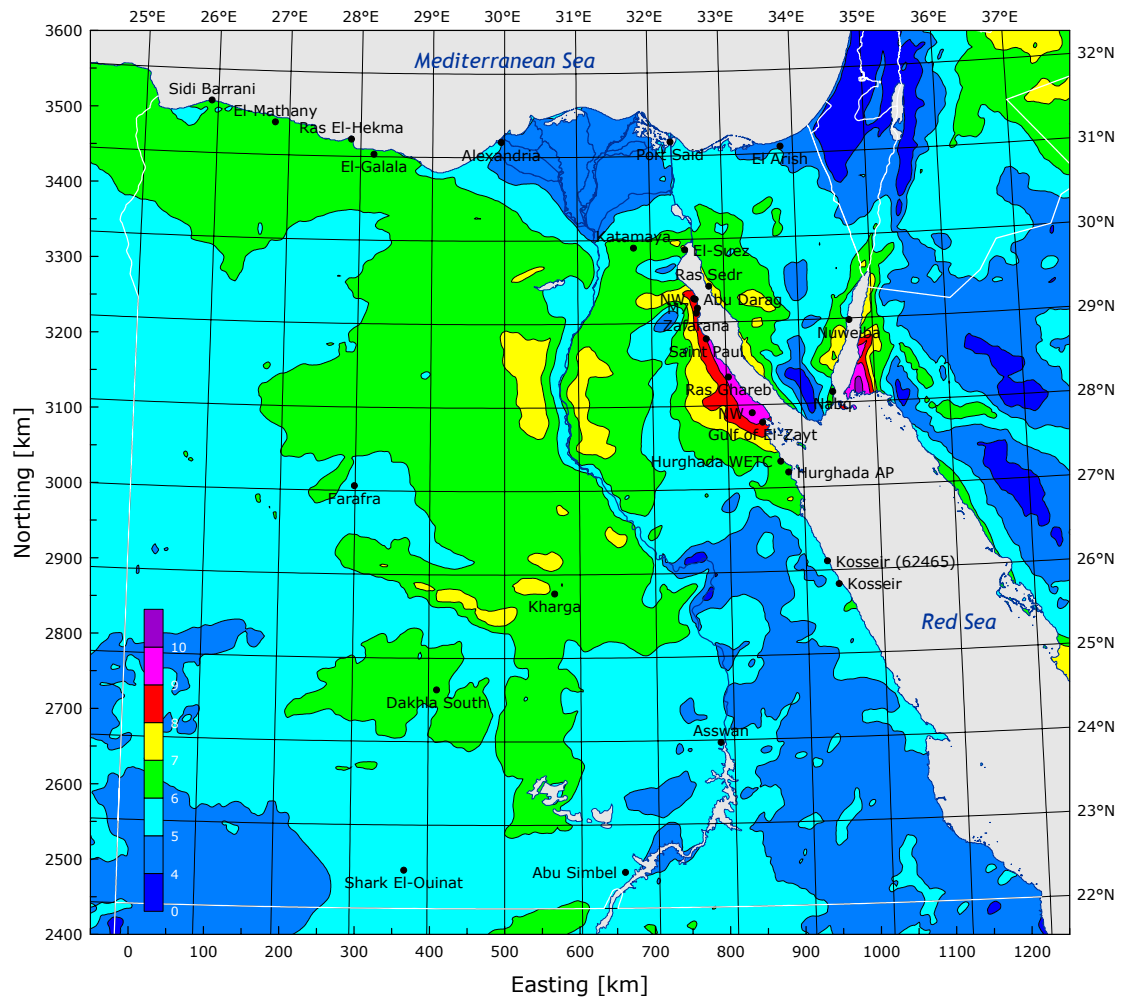


Figure 4. Wind resource map of Egypt: mean wind speed at 50 m a.g.l. determined by mesoscale modelling (Wind Atlas for Egypt, 2006).

This inherent limitation of the mesoscale model results can be overcome by transforming the wind resource map into a wind atlas map – or a numerical wind atlas – which can then be applied with a microscale model to reliably estimate the wind resource at any site within Egypt. In a sense, each grid point of the mesoscale model is treated as ‘virtual met. station’ from which the regional wind climate can be determined by an analysis procedure similar to the ‘up arrow’ in Figure 2. Conceptually, the mesoscale modelling therefore corresponds to covering Egypt with over 50,000 ‘virtual met. stations’ from which the regional wind climates can be determined. The numerical wind atlas is thus a database of regional wind climates and the Wind Atlas for Egypt contains exactly 54,897 regional wind climate data sets that can be employed directly with the WAsP microscale model for resource assessment and siting all over Egypt.

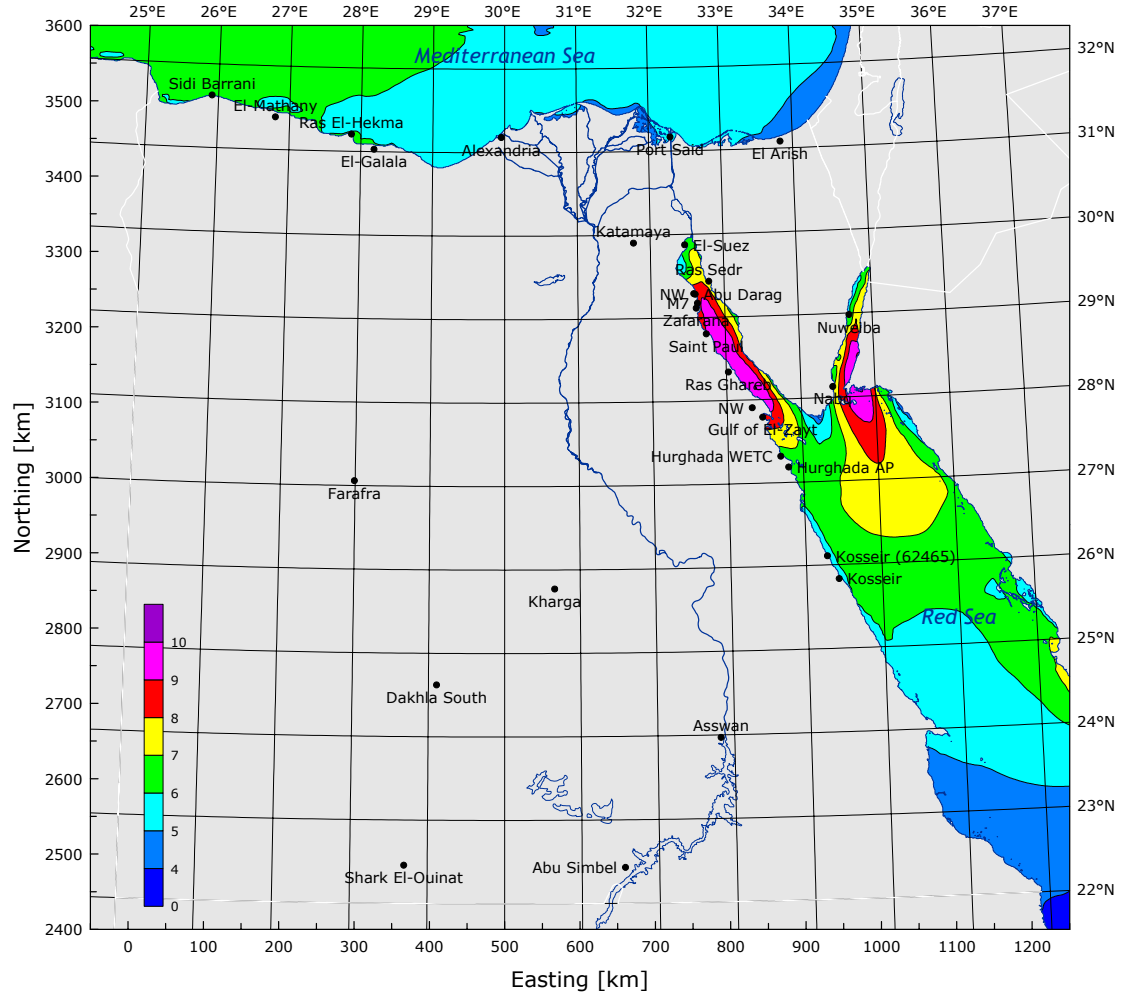


Figure 5. Offshore wind resource map of Egypt: mean wind speed at 50 m a.g.l. determined by mesoscale modelling (Wind Atlas for Egypt, 2006).

4. Verification

Since the observational and numerical wind atlases both result in estimates of the regional wind climate – i.e. the wind climate that would have been measured at a site if the terrain was flat and homogeneous and without any nearby obstacles – the regional wind climate values can be compared at the locations of the meteorological stations. Comparisons for six different domains in the Wind Atlas for Egypt indicate that the mean absolute error (the difference between the two estimates divided by their mean value) is typically around 10% for the two large-scale domains which cover all of Egypt, see Figure 6. For four smaller regional domains, the mean absolute error is typically around 5%, see Figure 7. The numerical wind atlas is less accurate in regions where the horizontal gradients in the regional wind climate are large, e.g. in the southern part of the Gulf of Suez and the northern part of the Red Sea, and also close to the domain boundaries.

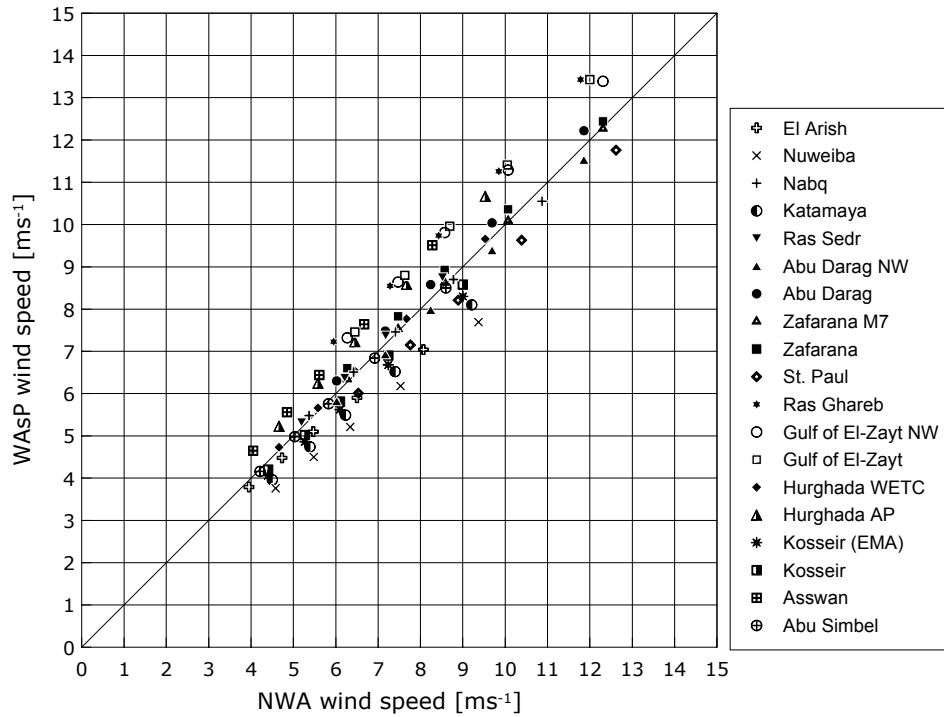


Figure 6. Eastern Egypt domain (resolution 7.5 km) comparison of atlas wind speed values at 10, 25, 50, 100, 200 m calculated using KAMM/WAsP (x-axis) and observations/WAsP (y-axis), roughness is 0.03 m.

However, the generally good agreement between the regional wind climates derived from mesoscale modelling and from observations adds confidence to the KAMM-derived wind statistics for locations away from the meteorological stations.

5. Summary and Conclusions

The Wind Atlas for Egypt represents a significant step forward in the application of the wind atlas methodology in Egypt. Not only does it provide a coherent and consistent overview of the wind energy resource over the entire land (and sea) area of Egypt, the results of the mesoscale modelling are further available in a database (numerical wind atlas) that may be employed directly for detailed wind resource assessments and siting of wind turbines and wind farms. Utilising this database together with elevation maps derived from the Space Shuttle Topography Mission and land-use maps constructed from satellite imagery, the wind resource and likely power production of a given wind farm can be estimated in a matter of hours – anywhere in Egypt.

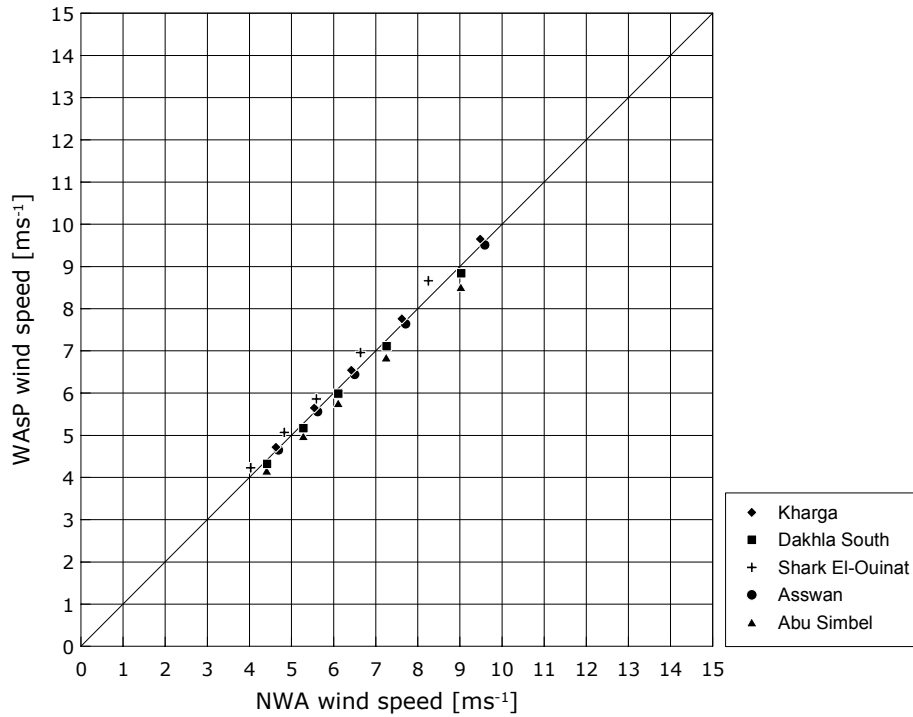


Figure 7. Western Desert domain (resolution 5 km) comparison of atlas wind speed values at 10, 25, 50, 100, 200 m calculated using KAMM/WASP (x-axis) and observations/WASP (y-axis), roughness is 0.03 m.

The numerical wind atlas methodology may not meet bankable accuracy in resource estimates, but on the other hand will typically give good indications of the geographical distribution and magnitude of the wind resource. It will therefore be useful for decision making, identification of new measurements sites, planning of feasibility studies and for actual project preparation. In areas where wind atlas stations are in operation, such as in the Gulf of Suez and along the Northwest Coast (Figure 1), the resource estimates may meet bankable accuracy – though this has to be confirmed on a project by project basis.

An important aspect of the Wind Atlas for Egypt project is its sustainability: the present approach to wind resource assessment and siting may be continued for several years to come. The observational wind atlas can be extended by continuing measurements at some stations and by moving other stations to new and promising sites. As the measurements series become longer and the number of sites larger, it will be important to establish wind index information for different parts of Egypt. The long-term quality of the measurement program can be maintained at a high level because a cup anemometer rehabilitation and recalibration facility has been established at the

Hurghada Wind Energy Technology Center. The numerical wind atlas, on the other hand, is based on long-term data (1968-95) and therefore does not need to be updated any time soon.

The *Wind Atlas for Egypt – Measurements and Modelling 1991-2005* (Mortensen et al., 2005) is available from the New and Renewable Energy Authority in Cairo, Egypt. In addition to the 258-page book, a comprehensive database of observed and regional wind climates is also available on CD-ROM.

6. Acknowledgements

The *Wind Atlas for Egypt* is the result of a comprehensive team effort. We therefore acknowledge the contributions of our colleagues in the project: Laila Georgy Youssef, Ashour Abd El-Salam Moussa and Mohammad Akmal Mahmoud from the New and Renewable Energy Authority; Ahmed El Sayed Yousef, Adel Mahmoud Awad, Mahmoud Abd-El Raheem Ahmed, Mohamed A.M. Sayed, Mohamed Hussein Korany and Metwally Abd-El Baky Tarad from the Egyptian Meteorological Authority; J. Carsten Hansen, Bo H. Jørgensen, Charlotte B. Hasager, Uwe S. Paulsen, Ole F. Hansen, Karen Enevoldsen from Risø National Laboratory.

The *Wind Atlas for Egypt* is sponsored by the governments of Egypt and Denmark. The Danish contribution to the project and the publication of the atlas are funded by the Danish Ministry of Foreign Affairs through Danida.

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